WELDING INSTITUTE OF CANADA

INSTITUT DE SOUDAGE DU CANADA

STUDY OF WELDING FUME CHARACTERISTICS OF COPPER-NICKEL ALLOY GAS METAL ARC ELECTRODES

Report RC-141

HEAD OFFICE:

391 BURNHAMTHORPE ROAD EAST/OAKVILLE, ONTARIO L6J 6C9

TELEPHONE: (416) 845-9881

REQ. NO. 2-9061

WELDING INSTITUTE OF CANADA
INSTITUT DE SOUDAGE DU CANADA

391 BURNHAMTHORPE RD. EAST, OAKVILLE, ONTARIO L6J 6C9 TELEPHONE (416) 845-9881

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Prepared by: S. Price
A. Ditschun, P.Eng.

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Approved by:

Dr. A. G. Glover,
Director, Technology

Study of Welding Fume Characteristics of Copper-Nickel Alloy Gas Metal Arc Electrodes

Final Report

by

Welding Institute of Canada

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ABSTRACT

Copper-nickel alloys are typical marine application materials because of their corrosion resistance. Arc welding of these materials produces airborne particulate fumes which may exceed recommended levels of concentration. This study examines the fume generation characteristics during gas metal arc welding of two 70/30 copper nickel alloys modified with Nb or Cr. This data can be of assistance in assessing the air quality in environments where these materials would be welded.

A STUDY OF WELDING FUME CHARACTERISTICS OF CU-NI ALLOY GAS METAL ARC ELECTRODES

Report RC-141

1.0 Introduction

The potential of adverse health effects from exposure to welding fumes is receiving greater attention from welders as well as management and it is in the best interests of worker safety and corporate productivity to maintain airborne concentrations of pollutants in welding environments within the established guidelines (1).

In order to evaluate the degree of control required, it is first necessary to understand the characteristics of fume production and how they are affected by variations in welding parameter. The objective of this study is to establish these characteristics for gas-metal arc welding of chromium and niobium modified 70/30 Cu-Ni alloys so that concerned personnel are better able to assess the requirements for providing cleaner welding environments.

2.0 General Characteristics of Welding Fume

2.1 Formation

The term "welding fume" generally refers to airborne microscopic particulate and gaseous matter. Welding processes and related operations produce both particulate and gaseous fume emissions as a result of one or more of the following factors:

i) Vaporization of the electrode and base metal constituents

ii) Oxidation of condensed vapour with atmospheric or shielding gas constituents

iii) Photochemical reaction of atmospheric gases caused by ultraviolet radiation

The airborne pollutants which are produced will vary in quantity, composition and toxicity and will be a function of the composition of the consumables and base plate, the welding process and the welding operating conditions. The consumable and base metal composition will largely control the composition of the fume which is produced. While the welding process which is being used will, to a large extent, control the rate at which particulate fume is produced.

2.2 Effect of Welding Parameters on Fume Production

Welding parameters such as voltage, current, and shielding gas have been shown to influence the fume generation rate (2, 3). Heile and Hill

investigated the dependence of fume formation on voltage, current, and travel speed, and included a study of the sources of error associated directly with the sampling technique (3). They observed that small variations in work travel speed from standard values had no significant effect. Depending on the shielding gas used, voltage and current were by far the most important factors among the welding parameters in determining the fume generation. For argon based shielding gas, a 1% to 5% variation in voltage for a fixed current produced changes in the fume generation rate of as much as 20%.

Heile and Hill also investigated the sensitivity of the measured fume generation rate to the sampling period. They revealed that inherent variations in the filter material caused their measured results to be time dependent. Absolute measurements of fume generation rates were subject to large variations, and voltage and current had to be precisely determined and maintained for experimental reproducibility. Differences from filter to filter, they reported, accounted for the largest and least controllable variation. As a result, they summarized that fume generation rates can be conveniently determined with an accuracy of 20%.

2.3 Fume Sampling and Detection Methods

The principal objective of the sampling of welding fumes is to assess the extent of personnel exposure to potentially harmful fume concentrations. In practical situations, the determination is carried out by the use of small pumps which collect airborne particulates on a filter media. Generally, two types of sampling procedures are used in practice. Breathing zone samples are taken with the sampling probe situated behind the welders helmet. These measurements are believed to be a realistic representation of the actual exposure received by an operator. Background samples can be taken at distances remote from the welding arc and they help to identify the exposure potential of individuals not directly involved in the welding operation. For background samples, the probes are placed 1.8 m above floor level.

A commonly used piece of equipment for these types of measurement consists of a battery powered pump drawing air through a filter at some predetermined rate; usually fixed between 1.5 - 3.0 litres per minute. Several models are commercially available. Similarly there are several possible filter materials and once certain criteria are fulfilled the choice is personal preference. A filter must collect all particles of the size range encountered in welding fume (usually 0.5 - 3.0 microns),and be compatible with the method of chemical analysis since dissolution or combustion of the filter is required in some analytical techniques.

To date there is no way to accurately estimate operator exposure because of the large number of uncontrollable variables that are present in any situation. These would include such factors as the variation of particulate concentration across a cloud of welding fumes, the position of the welder's head with respect to the arc, the type of process, the length of the duty cycle and several other considerations. For these and other reasons, the most realistic measurements of exposure must be done under actual field conditions.

In order to remove these variables from the present study another sampling method was used to provide a relative assessment of the fume emission potential from the various welding procedures under study. This technique involves collection of the fume particulate generated while welding for a short duration. If the weight of the fume collected can be determined and if the weld duration is known then the rate of fume generation can be calculated. Thus an estimation of the total fume loading in an environment over a given period of welding time can be determined which could be very useful in assessing the ventilation requirements for a specific application.

2.4 Potential Health Effects of Exposure to Welding Fumes

If it is acknowledged that exposure to particulate and gaseous by-products of the welding process may be potentially harmful to health, then two major categories of health effects must be considered. These are acute effects and chronic effects, and are brought on by short-term and long-term exposure respectively. These effects may be reversible or indefinite depending on the circumstances.

The short-term effects of welding fume on the health of the operator may vary from mild irritation of the eyes, nose and throat to nausea, fever, and severe cough. The effects will also vary according to the type of welding being undertaken, the conditions under which it is carried out, and the personal susceptibility of the individual. Acute reactions are often reversible and do not lead to long term disability but in the extreme some acute reactions can lead to asphyxiation.

There is a lack of conclusive evidence linking significant chronic health impairment solely to exposure to welding fumes. The most probable chronic effect of continuous and excessive exposure to welding fumes is a gradual deterioration of lung function. Establishing any positive correlations however, requires several years of subject monitoring and observation. In addition extraneous factors such as geographic location, previous exposure,

personal habits and natural aging effects must be isolated from the analysis. Overall, the available evidence is inconclusive which would suggest minimal chronic effects of exposure to welding fumes except perhaps in cases where the subject is a smoker or other uncommon circumstances are prevalent. These could include cases of prior exposure to substances not normally related to welding such as asbestos. A summary of classification of various possible welding fume constiuents with respect to potential acute and chronic effects on the body appears in Appendix A.

With regard to exposure to copper welding fumes, there does not seem to be a long term ill health effect, but the potential of acute reactions reflects the need to control the levels of copper fume in the workroom atmosphere. Excessive exposure to fumes from the welding of copper and its alloys can produce a malaise known as "copper fume fever". Symptoms include an irritation of the upper respiratory tract, a metallic or sweet taste accompanied by nausea, a tightness of the chest and fever. These symptoms are similar to metal fume fever which can be induced by exposure to other heavy metals such as zinc but are usually of not more than two days duration. Recommended levels of exposure to airborne contaminants are published by the American Conference of Governmental Industrial Hygientists (1) and a discussion on this is presented later in this report.

2.5 Potential Control Methods of Airborne Pollutants

As one of the objectives of fume sampling could be to address ventilation requirements, a brief introduction to the available options is warranted here. Removal of welding fume in an industrial operation is a difficult task if it is to be performed efficiently and economically. Several methods are available which may or may not employ filtration and recirculation of air. When air filtration is deemed feasible, the equipment operating options are limited to electrostatic or mechanical filtering techniques. Each method has inherent advantages and disadvantages. The selection of equipment type, size and distribution in a plant environment depends on several factors and consequently, the optimum solution depends uniquely on the application.

With regard to welding of copper-based materials, the precautions required will obviously depend on the alloy and joining process. Typical control procedures (4) are outlined below.

1) Non-arc welding processes or fully enclosed automatic welding processes such as diffusion bonding, friction welding, resistance welding, electron beam welding would in most cases require no ventilation. Some precautions may be required when the base material contains toxic alloying additions, eg. Cd, Be.
2) Open arc welding processes or cutting and brazing processes would not require precautions if performed out-of-doors. Welding and cutting indoors would require good general workshop ventilation and

good local extraction to maintain copper and other pollutants in the workshop atmosphere below their respective Threshold Limit Values (TLV's). In addition, the welder should also be protected by a dust mask. For long periods in confined spaces, the welder should be equipped with full respiratory protection, typically an air-line respirator. When Be or Cd are present the operator must always wear respiratory protection, even out of doors. If the potential for exposure to Be or Cd occurs inside it may be necessary to consider the protection of auxilary workers also.

A guide to the selection of respiratory protection is given by BS4275 (5). The Canadian Standard CSA W117.2 (6) lists ventilation requirements for welding, cutting and brazing.

The joining of copper is generally a safe procedure provided adequate ventilation and respiratory precautions are used. In case of doubt regarding which steps are necessary to ensure safe procedures, industrial hygiene professionals should be consulted, and on site fume and gas concentration measurements made if deemed necessary.

3.0 Experimental Details

3.1 Equipment

Bare wire electrodes of two different alloy types were evaluated for their capacity to produce fumes during gas-metal-arc welding, one modified with addition of niobium (Cuprotrode 521) and the other with addition of chromium (Monel 451). Chemical analysis of these consumables appears in Table 1. The base material was supplied by Physical Material Research Lab. (PMRL) in the form of cast plates (29.5 cm x 14.5 cm x 2.5 cm) with one bevelled edge. Heat #2467 consisted of Nb-modified alloy plates and heat #2470 consisted of Cr-modified plates.

Welding was performed in the steel enclosure shown in Figure 1. This chamber was equipped with a Roots model 2506-J vacuum pump capable of drawing 324 m^3/h (180 cfm) of air from the enclosure at a static pressure drop of 50 mm (2 inches) of mercury. This chamber was used in all the welding experiments to determine the fume generation rate under various welding conditions. The welding fume was collected (at the top of the chamber) on Owens-Corning PF 105 fiberglass filters. Samples for chemical analysis were collected using small personnel monitoring pumps made by DuPont (model P2500) operating at 1.5 m^3/h. The filters used in this device were composed of mixed polyester resins and were manufactured by Millipore. These filters had a pore size of 0.8 microns and were 25 mm in diameter. Weight determination of fume samples was done using a Metler HK150 electronic balance.

A Tykron Phase IV commercial fume extractor was used in some experiments to assess this method of local fume control.

The power source used for all the welding trials was a Miller Deltaweld 450 constant potential power source. A Miller GA50 air cooled automatic torch was used in conjunction with this equipment.

3.2 Test Program & Measurement Procedure

a) Fume Generation Rate Measurement

A bead on plate deposit was made for each selected combination of welding conditions in the Welding Institute's fume collection chamber. In this procedure, a 20 cm x 25 cm fiberglass mat filter was weighed and then clamped into a fixture at the top of the chamber. The Roots vacuum pump was turned on when welding was started to draw the particulate fumes into the filter. After completion of the weld (about 20 or 30 seconds), the Roots pump was left running for one minute to ensure that all the fume particulates had been collected on the filter. The filter was then removed from the fixture and weighed to determine the amount of particulate fume collected. Dividing the fume weight by the welding time yielded the fume generation rate in grams per minute. At least three, and occasionally as many as six, repeat runs were made for each welding condition to determine a representative average value of the fume generation rate.

Table 2 summarizes the range of welding conditions used in this test program. They are typical of those normally used with Cupro-Nickel alloys and electrodes 1.6 mm in diameter. The surface residue on the base plate was removed by grinding prior to each weld. The plate support fixture located inside the collection chamber, shown in Figure 2, was inclined at about 60° to the horizontal because of space limitations and equipment restrictions. As a result, the bead shape was poor but this did not affect the fume generation rate measurements.

The appearance of a typical filter after a weld is shown in Figure 3. The distinct colour separation at the border of the filter indicates that a good seal was obtained between the filter and the clamping fixture. Also, the small depth of discolouration through the thickness of the filter is indicative of a high degree of particle retention.

b) Samples for Chemical Analysis

Fume samples for chemical analysis were collected by placing the sampling probe of the DuPont pump inside the welding chamber. The Roots vacuum pump was not used in this case so that fumes could accumulate inside the chamber. After a weld, the pump was allowed to run for several minutes until a visible deposit had been collected on the 25 mm Millipore filters. The weight of the fume was determined and the sample submitted for analysis. In this case, the filter material was dissolved in the analytical procedure.

Because this technique does not easily allow for weight compensation from water absorption by the filter material, a second collection method was also used. This method required that 20 cm x 25 cm Millipore filters be clamped in the same fixture used in the fume generation rate experiments. The Roots vacuum pump was used in this case, and after the sampling period, the particulate fume was scraped off the surface of the filter and weighed. All fume samples were submitted to Concord Scientific Corporation for chemical analysis using D.C. Plasma Optical Emission Spectroscopy.

c) Fume Control Tests

A series of experiments was also done to assess the effectiveness of a commercial fume extraction unit. A Tykron Phase IV portable fume extractor (Appendix B) was used for these tests. This unit could apply two rates of extraction at 270 m^3/h (160 cfm) and 135 m^3/h (80 cfm). The fume pick-up nozzle had a circular cross section of 9 cm diameter. To evaluate the amount of fume this equipment could typically capture, the following test sequence was applied. The local pick-up nozzle was placed directly above the welding arc in two separate tests at distances of 18 cm and 30 cm. With both the local extractor and the Roots vacuum operating, a weld was performed. The fume which by-passed the local pick-up was collected on the fiberglass filter in the fume chamber. The apparent fume generation rate was calculated following each test, and compared with the rate observed when no local extraction was applied. In this way, the fume capture efficiency of the local extractor could be assessed.

3.3 Calibration Test

To establish the accuracy of the experimental technique used in this study, a calibration procedure as defined in AWS F1.2-79(7), was conducted. In this test an E70S-3 electrode of 1.2 mm diameter was used at a wire feed speed of 127 mm/s (300 in/min) at 225A with reverse polarity using a constant potential power source. A 19 mm electrical extension and 10° lagging torch angle were used with CO_2 shielding gas at a flow rate of 19 litres per minute (40 ft ^{3}/h) with a 19 mm diameter gas nozzle. Four bead on plate welds were performed and the fume generation rate was determined after each bead.

The average of two calibration tests performed at the Welding Institute of Canada, using 24 V, was 0.39 g/min. This is comparable to the AWS standard test result of 0.43 g/min (AWS F1.2.79). Similarly, for 26 V, the average fume generation rate was 0.58 g/min while the AWS standard gave 0.55 g/min. This experimental accuracy of 5% - 10% is well within the predicted limits of Heile and Hill (3).

4.0 Experimental Results

4.1 Fume Generation Rates of the Monel 451 Electrode

A summary of the welding conditions and resultant fume generation rates when using 100% argon shielding are given in Table 3. When plotting these fume generation rates as a function of voltage (Figure 4), it can

be seen that generally an increase in voltage gave an increase in fume generation rate, particularly at the higher voltages. Further, when the current levels were increased for a given voltage, the fume emission rate increased (Figure 5, 6). The fume generation rate observed for the welds made at the highest voltage and current was over three times greater than that of welds made with the lowest current and voltage combination as shown in Table 3. Thus, it is apparent that the quantity of fume produced is a function of both current and voltage.

The results of bead on plate welds made with a 50/50 argon-helium mixture are summarized in Table 4. Plotting the fume generation rates against voltage in Figure 7 shows the tendency to peak fume evolution at 29 V with a decrease at higher voltages. At the lower current ranges, greater amounts of fume were generated for each of the considered voltages as shown in Figures 8 and 9. The lowest recorded fume generation rate (0.37 g/min) was obtained when using 350A and 31 V.

4.2 Fume Generation Rates of the Cuprotrode 521 Electrode

The results of bead on plate welds with 100% argon shielding are summarised in Table 5. When plotting this data as a function of welding voltage, marked variation was apparent for the different current levels tested as shown in Figure 10. Some current levels indicated increasing fume generation rate with increasing welding voltage while others showed a decreasing trend. As before, the general tendency towards a higher fume generation rate with an increase in current was observed at 27V as illustrated in Figure 11. At 29V, Figure 12, there is a slight decrease

followed again by an increase. In particular, with a current of 370 A the fume generation rate was well over 0.60 g/min for all voltage levels as shown in Figure 10. The fume emission for currents between 280 and 320 amps for all voltages was substantially lower than this.

The smallest fume generation rate was obtained at 300A and 29 V (0.25 g/min). Generally, the fume generation rates were approximately 30% higher than for Monel 451 wire.

The resultant fume generation rates when 50/50 argon-helium shielding gas is used are summarised in Table 6. Figure 13 illustrates the trend of fume generation rate with increasing voltage, showing basically a slight decrease at the higher voltages with the exception of 280A. Comparing these to Figure 7 shows the major difference to be that the values for the Monel 451 were lower. It was also observed that as the current increased, the fume generation rate rose to a maximum near 300 amps and then decreased slightly as shown in Figures 14 and 15. As with the tests on Monel 451, the 50% argon + 50% helium produced a fume generation rate three times greater than that produced with 100% argon.

4.3 Chemical Analysis of Welding Fume

The results of the chemical analyses on the welding fume samples is shown in Table 7. For the Cuprotrode 521 and 100% argon, the copper content ranged from 21% to 89%. One sample taken with the argon-helium mixture yielded 25% copper while a second sample returned an impossibly high (in excess of 100%) result. With this large variation, it is not

possible to conclude whether the gas changes in shielding gas mixture had any effect on the fume chemistry. Since the welding parameters were also similar, they could not be accountable for the large range of values. The only possible explanations are that either some fume was lost between the weighing and the analytical stage or that moisture absorption by the fume (or filter) was not accounted for in the weight determinations.

The copper content in the Monel 451 welding fume varied between 37% and 82% when using 100% argon gas which is similar to that obtained with the Cuprotrode 521. With a 50/50 argon-helium mixture, the copper fraction in the Monel 451 welding fume was 44%.

The nickel fraction in the fume varied from about 6% to 48% for the Cuprotrode 521 welding fume. The nickel fraction in the Monel 451 welding fume ranged from about 7% to 14%.

With both the nickel and copper fractions, the range of values was too great to establish any dependance on the shielding gas composition.

It can be concluded that the compositions determined for sample numbers 1, 4 and 6 are incorrect for the following reasons. Sample numbers 1 and 4 have a sum total of copper and nickel fraction greater than 100% which is not possible. Sample number 6 with a sum of 91% of copper and nickel, cannot be realistic because oxygen, which must be present in the

oxidized particulate fume, would constitute at least an additional 25% of the total and thus, produce a total fraction in excess of 100%. This figure of 25% for the oxygen fraction is approximated on the basis that:
a) the atomic weight of oxygen is roughly one quarter that of copper or nickel and,
b) the particulate fume is actually a compound of oxidized copper and oxidized nickel.

Thus, excluding these samples from the results and taking an average of the remaining figures, the copper content is approximately 30% and the nickel content is about 7% for the Cuprotrode 521 welding fume. The Monel 451 welding fume composition is averaged to 41% copper and 10% nickel.

4.4 Fume Control Tests

For these experiments only the lower extraction air flow rate of the Tykron machine could be tested because of electrical constraints. Table 8 summarizes the results of these tests. As would be expected, when the extraction nozzle was 18 cm from the welding arc, it captured more fume than at 30 cm. At the 30 cm distance, it was totally ineffective since no change in the average fume generation rate was observed. At 18 cm, a reduction of 27% in fume generation rate was calculated. Thus, when using this type of local extraction equipment, the nozzle should be situated as close as possible to the welding arc for optimum capture

efficiency. It has been established (6, 8) that the air velocity required to effectively transport or remove fume particles is about 0.5 metres per second. On this basis, air flow measurements at the nozzle can be made to establish effective working distances from the welding arc for various types of extraction equipment. A realistic distance from the arc when applying the equipment used in this study would be from 7 cm to 12 cm. Specially designed GMAW guns that incorporate a fume exhaust capability would be appropriate for this application since the exhaust intake is close to the arc. This adaption adds some bulk and weight to the gun but is not sufficient to impair its handling ability.

5.0 Discussion

The results demonstrate the dependence of the fume generation rate on the welding parameters, the shielding gas and the alloy composition. Overall, the fume generation rate varied from about 200 mg/min to over 1000 mg/min. The shielding gas selection had the most pronounced influence on the emission rate of the fumes with the 50/50 argon-helium mixture producing two to three times more fume than with 100% argon. Since both gases are chemically inert, this result could be related to the fact that helium is a lighter gas. This could produce greater turbulence due to gas expansion in the arc vicinity resulting in aspiration of atmospheric gas. This in turn would make greater quantities of oxygen available for reaction with vapourized metals in the arc.

Variations in the welding parameters (current and voltage) did not have a consistent influence on the fume generation rate. For example, higher current and/or voltage generally resulted in increased fume production when using 100% argon and Monel 451. A 50/50 argon-helium mixture with this alloy produced more fumes as the voltage increased to 29V. Higher voltages than this seemed to reduce the fume production although voltages of this magnitude are not used in normal practice. Increases in current with this gas mixture did not have as pronounced an influence on the fume production. If it is assumed that a 20% band of error exists (3), then for practical purposes the fume generation rate is independent of current.

With the Cuprotrode 521 alloy and 100% argon, voltage changes for a given current, did not appear to have a significant influence on the fume production. Increased current, however, did produce greater fume emissions. As with the Monel, the 50/50 argon-helium mixture increased the fume generation rate but the general trends with current and voltage variations are not consistent with previous observations. A possible factor that could account for the varying trends is the day to day variation in relative humidity. Controlled experiments to determine the influence of this factor have not been done although the available literature (2) suggests relative humidity could affect the fume generation rate.

The results of this work do indicate that, for identical welding conditions, the Cuprotrode 521 generally produced more particulate fume than the Monel 451, by as much as 50% in some cases. The chemical

composition of the welding fumes from both alloys appear to be relatively similar with regard to copper and nickel content.

In order to develop a perspective of the significance of the fume generation rate and fume composition, an understanding of industrial hygiene guidelines is necessary. Generally accepted guidelines for industrial exposure to airborne pollutants are published by the American Conference of Governmental Industrial Hygienists (ACGIH) and they are referenced by the CSA W117.2 "Code for Safety in Welding and Cutting". The recommended average daily limits of exposure to substances are called Threshold Limit Values (TLV). These TLV's represent the conditions under which it is believed that most workers can be exposed to substances day after day without suffering adverse health effects. The values are established from monitoring industrial experiences and animal experimentation. They should not be interpreted as absolute quantities which guarantee freedom from observable health effects since individual sensitivities should take precedence in establishing acceptable levels. Table 9 lists several substances and the corresponding ACGIH exposure limits. The figures, expressed in units of mg/m^3 for particulate fumes and parts per million (ppm) for gases, represent the maximum recommended 8 hour time-weighted-average (TWA) concentration of worker exposure. The ACGIH recommends that the average daily exposure to total welding fumes be limited to 5 mg/m^3. Individual constituents in the fume, however, must also be below their respective TLV and in some situations the 5 mg/m^3 level for a total fume content is too high to

achieve this. In this case, measures should be taken to reduce the total fume concentrations so that the recommended constraints are satisfied for the individual fume elements. Under certain circumstances exposure to two or more potentially hazardous substances may require that a threshold limit value for mixtures be applied. Identifying situations where this would be applicable would require consultation with Ministry of Labour officials. For additional information, the reader is referred to the ACGIH publication "Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment". It should be noted also that the Ontario Ministry of Labour is considering adopting their own version of the ACGIH recommendations. This document, entitled "Exposure Criteria for Potentially Harmful Agents and Substances", is still under discussion and constructive comments are encouraged by the Ministry.

Since the ACGIH recommendation of a maximum exposure level to total welding fume of 5 mg/m^3/day represents an acceptable level of workroom contamination, with the stipulation that individual fume constituents be below their respective TLV's, it is possible to perform simple calculations to estimate whether these levels are easily exceeded during a welding operation.

The acceptable total fume concentration is 5 mg/m^3 whereas the acceptable copper level is 0.2 mg/m^3. Thus, if the copper generation rate is less than 4% (0.2/5 x 100%) of the total fume generation rate then the

total fume concentration is the critical indicator for acceptable levels. Based on the chemical analysis, the copper content of the fumes was generated at a rate of 30% to 40% of the total. Therefore the copper concentrations will exceed the copper TLV of 0.2 mg/m^3 long before the total fume concentration is 5 mg/m^3. In fact, assuming copper constitutes 30% of the fume, the copper TLV will be exceeded when the total fume concentration is 0.7 mg/m^3 or more.

On this basis, and taking for discussion purposes, an average of the fume generation rate of 0.25 g/min, a room 10 m x 10 m x 10 m would reach a concentration of 1 mg/m^3 after four minutes of welding if no ventilation was applied. If the copper fraction of this is 30%, then the copper concentration is 0.3 mg/m^3 or 50% higher than the TLV. This observation itself would suggest that some positive control of the fumes should be applied for extended periods of welding so that the recommended levels are not exceeded. The American Welding Society (2) has developed a graph that can be used to assess the level of general ventilation which may be required to achieve a given steady state concentration of fume for various fume production rates. This graph, illustrated in Figure 16, was developed purely from mathematical considerations and does not account for the settling out of the fume particles or uneven mixing. As such, the ventilation figures derived from the chart are probably more representative of an order of magnitude rather than of absolute values. In circumstances where local ventilation is used, this chart is not applicable.

The principles of industrial hygiene support the concept that substances having similar physiological influence can have synergistic effects on health. Circumstances where individuals may experience simultaneous exposure to several potentially toxic substances would then require a different approach to establish acceptable levels of exposure. In these cases, the exposure should be such that the following expression has a value less than one.

$$\frac{C_1}{T_1} + \frac{C_2}{T_2} + \cdots \frac{Cn}{Tn} < 1$$

Cn = observed atmospheric concentration for substance n

Tn = Threshold Limit Value of substance n

In relation to the welding conditions studied in this program there are three substances that affect the respiratory system (Appendix A). These substances are copper, nickel and ozone and their concentrations in a welding environment should be assessed on the basis of this mixture calculation. A proper evaluation of reasonable concentrations of total fume would best be done on site under actual welding conditions because the ozone concentrations vary greatly with distance from the arc. If the ozone contribution is small enough to be negligible then only the copper and nickel need be considered. Thus, using values of 30% and 10% for the copper and nickel fraction respectively, a total fume concentration of 0.6 mg/m^3 would satisfy the mixture TLV criterion since

$$\frac{30\% \times (0.6)}{0.2} + \frac{10\% \times (0.6)}{1} = 0.96$$

It should be noted that the applicable value for the nickel TLV from Table 9 is taken as $1 mg/m^3$ since the bulk of the nickel fume is insoluble. For practical purposes, nickel can probably be ignored since it does not contribute significantly to the "mixtures calculation". This occurs because it has a higher TLV and constitutes a lower fraction of the total fume concentration than copper. Therefore, in situations where ozone does not pose a problem, a total fume concentration of $0.6 mg/m^3$ should satisfy both the TLV's of copper and nickel.

6.0 Conclusions

1. For 100% argon shielding gas using the Monel 451 wire, the fume generation rate increased as a function of both current and voltage. The values ranged from 300 to 400 mg/min for typical welding conditions.
2. For 100% argon gas and with the Cuprotrode 521, the fume generation rate was generally higher than for the Monel 451. The rate of change in fume generation rate as a function of current was similar to that observed with Monel 451. The fume generation rate, however, was less sensitive for step increases in voltage for a given current.
3. The use of an argon and helium gas mixture (50/50), produced as much as a 300% increase in the fume level than with 100% argon under the same welding conditions.
4. With the 50/50 mixture, the trend of fume generation rate as a function of current is different from that observed with the pure argon gas in that a maximum value occurs around 300 A. With pure

argon the fume emission appeared to increase consistently with current.

5. The fume chemistry is approximately 35% copper and 10% nickel for both alloy compositions.
6. The spot extraction nozzle reduced the fume generation rate by about 30% when placed 18 cm from the arc.
7. In situations where ozone is not present, total fume concentrations of 0.6 mg/m^3 should ensure that the copper and nickel fume components are below their respective Threshold Limit Values.

7.0 Recommendations

1. Pure argon gas should be used in place of argon-helium mixtures.

2. Some method of ventilation control should be applied when welding with the Cupro-Nickel alloy materials.

3. On the basis of these results, the optimum welding parameters with 100% argon gas are 27V and 280A for the Monel 451 and 29V and 300A for the Cuprotrode 521.

8.0 References

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3. Heile, R.F. and Hill D.C., "Particulate Fume Generation in Arc Welding Processes", Welding Journal, Vol. 56, No. 7, July 1975, p 33 - 34.

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6. "Code For Safety in Welding and Cutting", CSA Standard W117.2, 1974.

7. "Laboratory Method for Measuring Fume Generation rates and Total Fume Emission of Welding and Allied Processes", AWS F.1.2. - 79, American Welding Society, 1979.

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11. Anonymous, "Electrostatic Precipitation for Welding Fume", Welding Journal, Vol. 59, No. 6, June 1980, p 41 - 42.

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TABLE 1

Chemical Analysis (wt.%) of Electrodes for Nb- and Cr- Modified 70/30 Cu-Ni Alloys

	Mn	Cr	Ni	Cu	Fe	Nb
Cuprotrode 521	0.72	0.01	27.60	66.62	0.74	0.55
Monel 451	1.98	1.81	25.87	66.45	0.39	0.01

TABLE 2

Summary of Welding Conditions Used in GMAW Welds in Both Nb- and Cr - Modified 70/30 Cupro-Nickel Alloys

Joint Design:	bead on plate
Electrode:	1/16 in (1.6 mm) dia Cuprotrode 521 for Nb-modified alloys 1/16 in (1.6 mm) dia Monel 451 for Cr-modified alloys.
Shielding Gas:	1) 100% Argon, 40 cfh - (1.2 m^3/h) 2) 50% Argon + Helium mixture 40 cfh (1.2 m^3/h)
Arc Voltage:	27 - 29 V (31 V for some experiments)
Current (D.C. Electrode Positive:	a) 270 - 370 Amp for Nb-modified alloys b) 270 - 370 Amp for Cr-modified alloys
Travel Speed: in/min(mm/min)	For 100% Argon a) 7.6 - 10.9 (195 - 275) for Nb-modified alloys b) 7.6 - 10.3 (195 - 260) for Cr-modified alloys For 50% Argon + Helium Mixture a) 8.7-10.7 (220 - 270) for Nb-modified alloys b) 7.9 - 13 (200 - 330) for Cr-modified alloys

TABLE 3

Fume Generation Rate During Bead on Plate Welds With a Monel 451 Electrode

Wire: Cr-modified Cu/Ni: 1.6 mm diameter.

Plate: #2470 (Heat number)

Gas: 100% Argon, 40 cfh (1.2m^3/h)

Current (A)	Voltage (V)	Wire Speed (mm/min)	Fume Generation Rate (g/min) Max	Min	Avg *
280	27	195	0.33	0.12	0.21
300	27	221	0.42	0.21	0.29
320	27	225	0.35	0.24	0.29
370	27	275	0.57	0.18	0.33
270/280	29	195	0.33	0.15	0.22
300	29	225	0.36	0.18	0.26
320	29	240	0.51	0.30	0.37
370	29	260	0.60	0.33	0.46
270/280	31	195	0.33	0.21	0.27
280	31	200	0.39	0.24	0.31
300	31	215	0.50	0.32	0.41
320	31	220	0.72	0.72	0.72

* Average of 4 to 6 tests

TABLE 4

Fume Generation Rate During Bead On Plate Welds With a Monel 451 Electrode

Wire: Cr-modified Cu/Ni: 1.6 mm diameter

Plate: #2470 (Heat Number)

Gas: 50% Argon + 50% Helium, 40 cfh ($1.2m^3/h$)

Current (a)	Voltage (V)	Wire Speed (mm/min)	Fume Generation Rate (g/min) Max	Min	Avg*
280	27	250	0.64	0.58	0.61
300	27	280	0.70	0.59	0.64
320	27	320	0.54	0.51	0.51
350	27	340	0.60	0.49	0.54
270/280	29	200	0.96	0.72	0.83
300	29	240	0.99	0.75	0.85
320	29	270	0.87	0.66	0.77
350	29	330	0.78	0.55	0.67
280	31	220	0.69	0.60	0.64
300	31	260	0.72	0.24	0.48
350	31	290	0.44	0.30	0.37

*Average of 4 to 6 tests

TABLE 5

Fume Generation Rate During Bead on Plate Welds

With a Cuprotrode 521 Electrode

Wire: Nb-modified Cu/Ni: 1.6 mm diameter.

Plate: #2467 (Heat Number)

Gas: 100% Argon 40 cfh (1.2 m3/h)

Current (A)	Voltage (V)	Wire Speed (mm/min)	Fume Generation Rate (g/min) Max	Min	Avg *
270/280	27	190	0.39	0.30	0.35
280	27	195	0.36	0.32	0.33
300	27	221	0.39	0.39	0.39
320	27	225	0.51	0.45	0.48
370	27	275	0.66	0.60	0.64
270/280	29	195	0.36	0.30	0.34
300	29	225	0.27	0.24	0.25
320	29	240	0.36	0.36	0.36
370	29	260	0.84	0.75	0.79
270/280	31	200	0.33	0.30	0.31
300	31	215	0.27	0.27	0.27
320	31	220	0.51	0.36	0.43
340	31	225	0.81	0.54	0.67

* Average of 4 to 6 tests

TABLE 6

Fume Generation Rate During Bead on Plate Welds With a Cuprotrode 521 Electrode

Wire: Nb-modified Cu/Ni; 1.6 mm diameter

Plate: #2467 (Heat Number)

Gas: 50% Argon + 50% Helium - 40 cfh ($1.2m^3/h$)

Current (A)	Voltage (V)	Wire Speed (mm/min)	Fume Generation Rate (g/min) Max	Min	Avg*
280	27	230	0.75	0.69	0.72
300	27	250	0.90	0.81	0.85
320	27	270	0.84	0.69	0.76
280	29	220	0.99	0.96	0.97
300	29	240	1.02	0.99	1.00
320	29	270	0.87	0.87	0.87
280	31	220	1.05	1.00	1.02
300	31	240	1.02	0.96	0.99

* Average of 4 to 6 tests

TABLE 7

Data Sheet for Chemical Analysis

Electrode	Sample No.	Fume Weight(gm)	Welding Conditions Voltage (v)	Current (A)	Chemical Contents (%) Copper	Nickel	Chromium	Shielding Gas
	1	0.0100	29	270	89.9	30	0.16	Argon
	2	0.0002	29	300	39.2	5.8	0.2	
Cuprotrode 521	3	0.0002*	29	300	21.6	6.7	0.5	
	4	0.03	29	300	N/A	48	0.13	Argon
	5	0.0954	29	300	25.4	8.3	0.025	+ Helium
	6	0.0009*	29	300	82	9		Argon
	7	0.002	29	270	37	6.5		
Monel 451	8	0.0148	29	300	44.1	8.7		
	9	0.0347	29	300	43.8	13.7		Argon + Helium

* Samples collected on the 25 mm filters.

TABLE 8

Test with the Tykron local extraction nozzle while using Cr-modified Cu/Ni electrode and 100% argon as shielding gas (300A, 29V).

Distance From the Nozzle	Fume Generation Rate (g/min) Low	High	Avg.
18 cm	0.12	0.21	0.19
30 cm	0.22	0.32	0.27
Without Tykron local extraction	0.18	0.36	0.26

Table 9
ACGIH Recommended Threshold Limit Values

SUBSTANCE	TLV
Aluminum (A1) Welding Fume	5 mg/m^3
Beryllium (Be)	0.002 mg/m^3
Cadmium Oxide Fume (Cd)	0.05 mg/m^3 (C)
Carbon Dioxide (CO_2)	5,000 ppm
Carbon Monoxide (CO) (Note 1)	50 ppm
Chromium (Cr)	
– Chromates, certain insoluble forms .	0.05 mg/m^3
– Chromium soluble chromic & Chromous Salts	0.5 mg/m^3
Copper (Cu)	0.2 mg/m^3
Fluoride (F)	2.5 mg/m^3
Iron Oxide Fume (Fe_20_3)	5 mg/m^3
Lead (Pb)	0.15 mg/m^3
Lithium Hydride	0.025 mg/m^3
Manganese Fume (Mn)	1 mg/m^3
Molybdenum (Mo)	5 mg/m^3
Nickel, Soluble Compounds (as Ni)	0.1 mg/m^3
Nickel Sulfide Roasting fume and dust (Ni)	1 mg/m^3
Nitrogen Dioxide ($N0_2$)	5 ppm
Ozone (0_3)	0.1 ppm
Phosgene (Carbonyl Chloride) ($COC1_2$)	0.1 ppm
Tin (Sn) inorganic compounds except Sn H & Sn 0_2	2 mg/m^3
Tin (Sn) organic compounds	0.1 mg/m^3
Vanadium Fume (V_20_5 as V)	0.05 mg/m^3 (C)
Zinc (Zn) Zinc Oxide Fume	5 mg/m^3
Total Welding Fume	5 mg/m^3

The Welding Fume Test Chamber

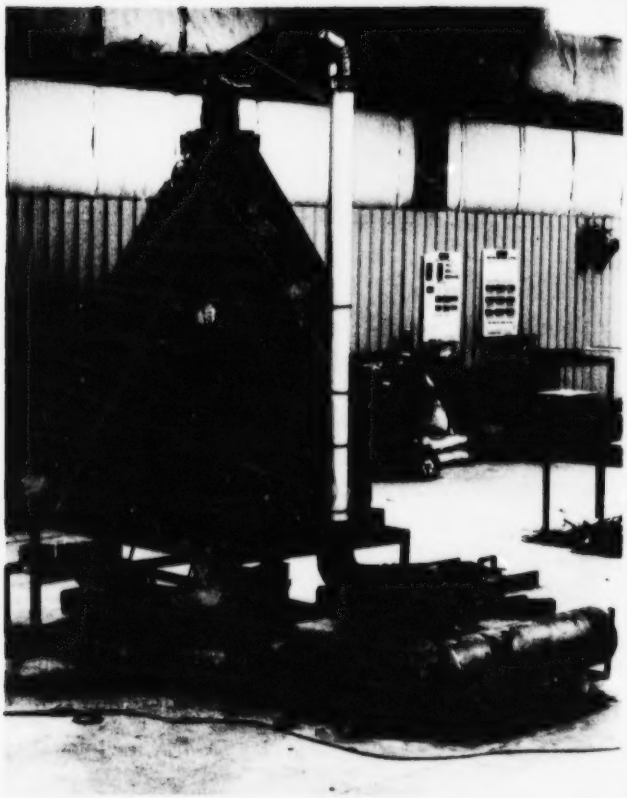


Figure 1: The welding fume chamber consists of a closed cabinet with a filter element at its apex. A vacuum pump draws air from the chamber through the filter which retains particulate welding fume.

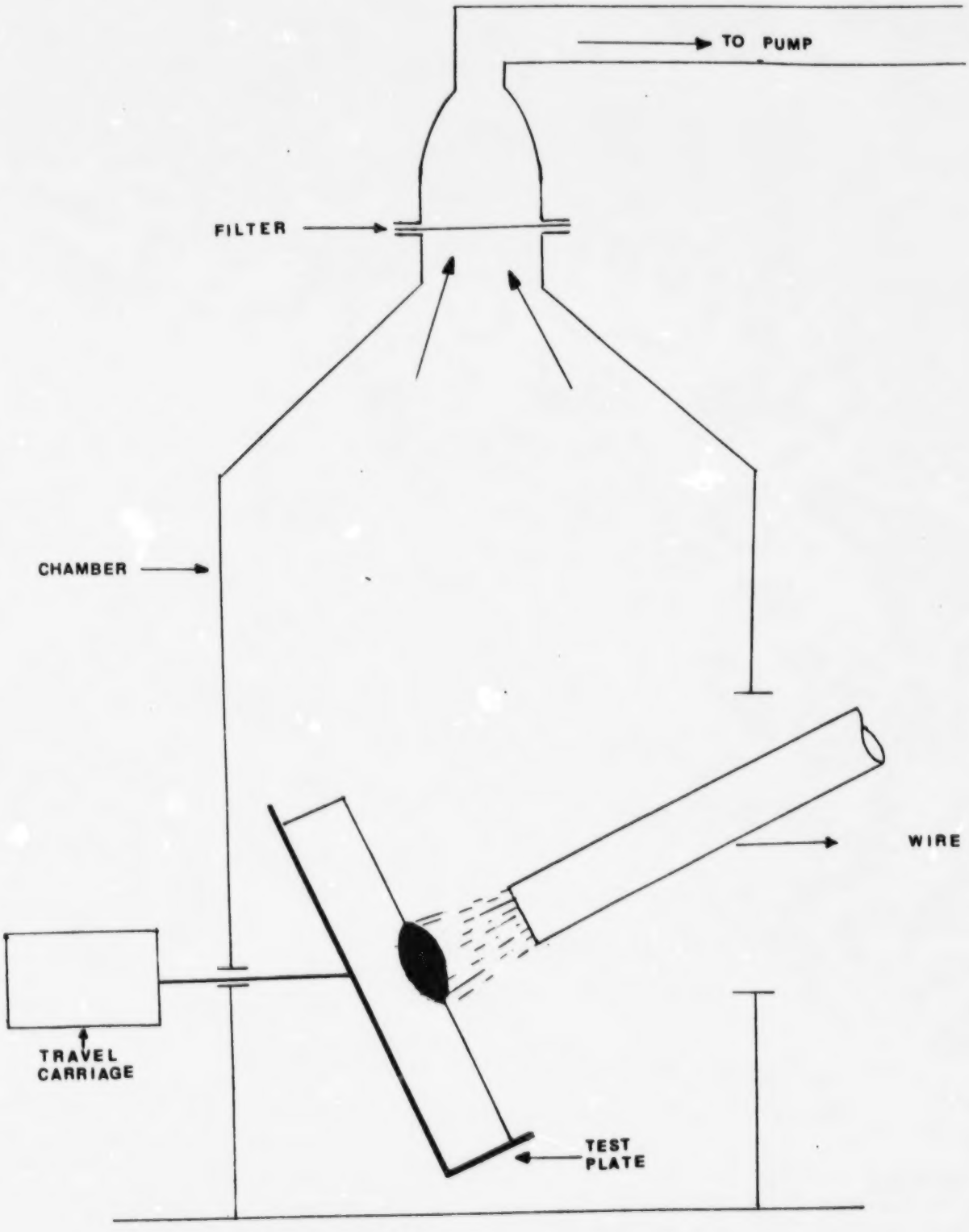


Figure 2: Schematic arrangement of the test equipment (not to scale)

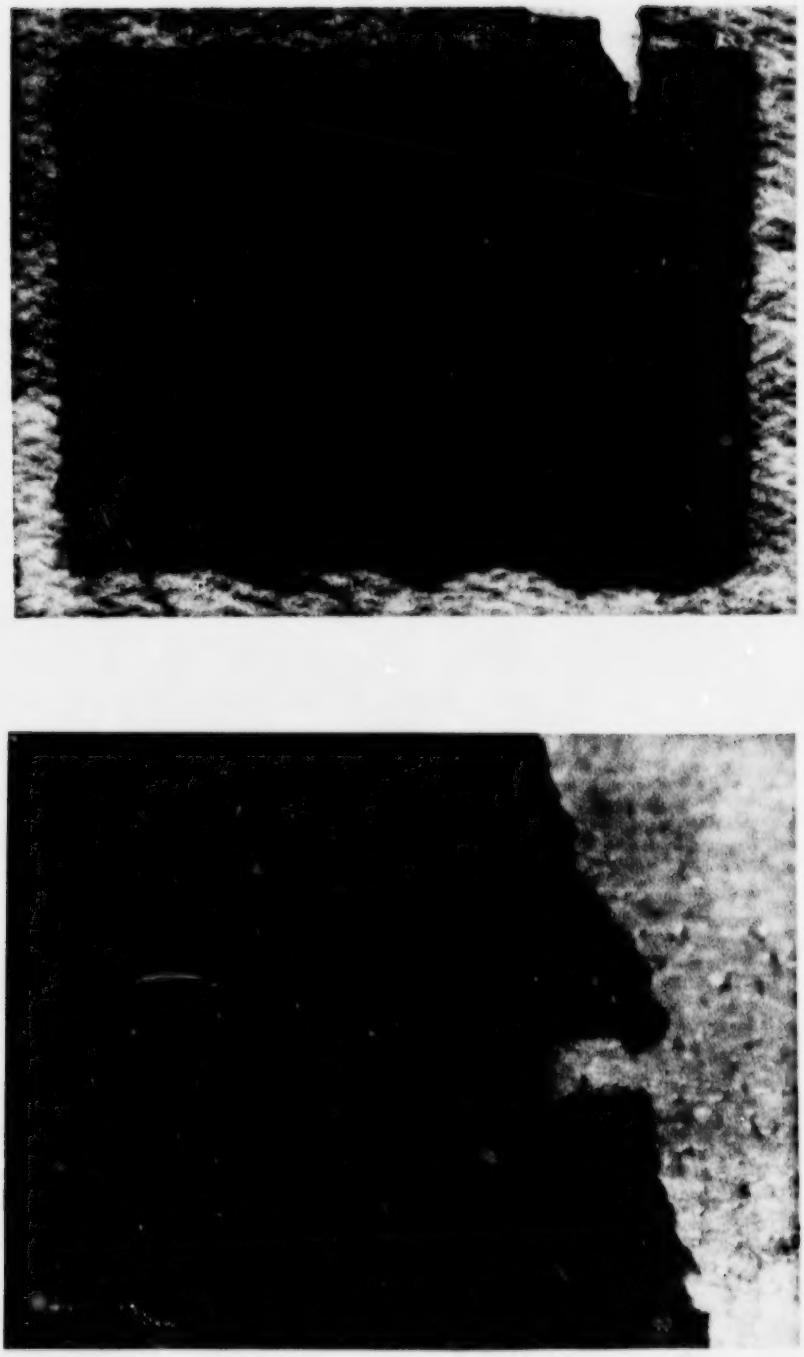


Figure 3:
A typical fume deposit on the filter after a welding trial.

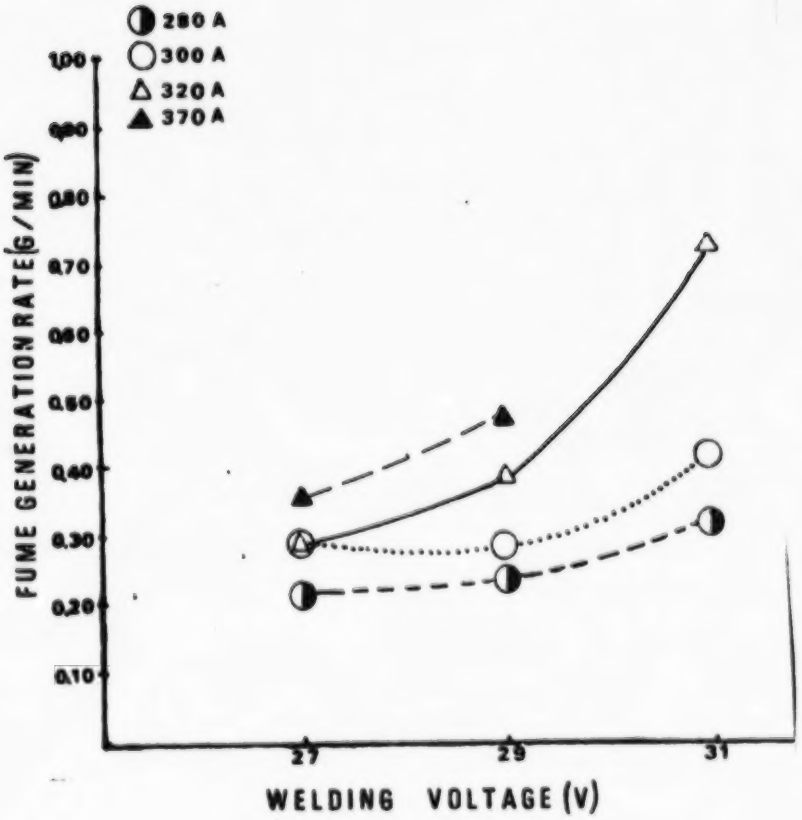


Figure 4. Average fume generation rate during welding with Monel 451 electrode at 280A, 300A, 320A and 370A welding current while using 100% Argon.

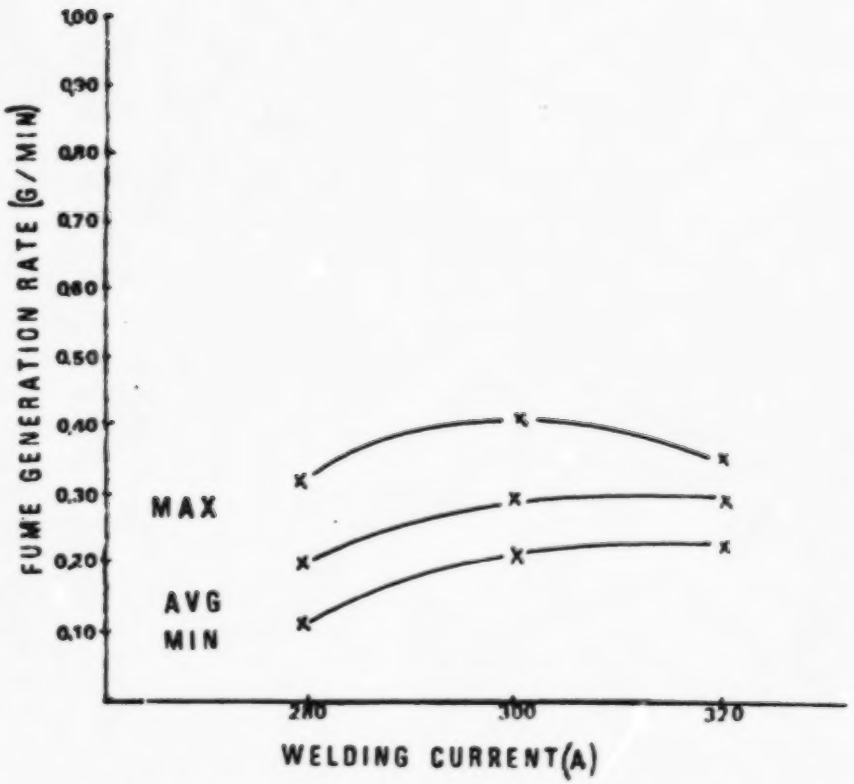


Figure 5: Fume generation rate during welding with Monel 451 electrode at 27V while using 100% Argon as shielding gas.

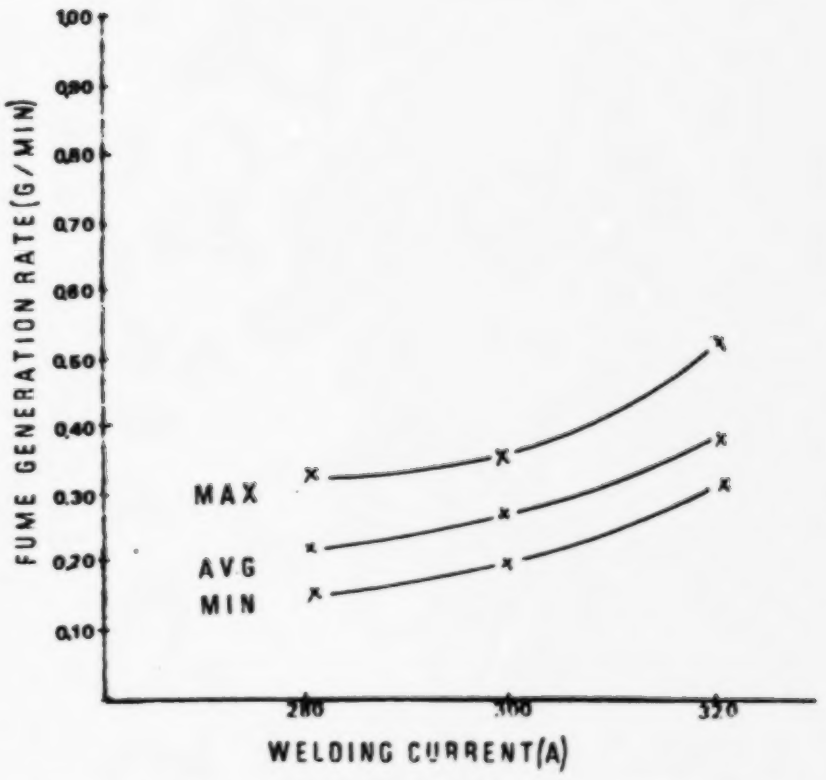


Figure 6: Fume generation rate during welding with Monel 451 electrode at 29V using 100% Argon as shielding gas.

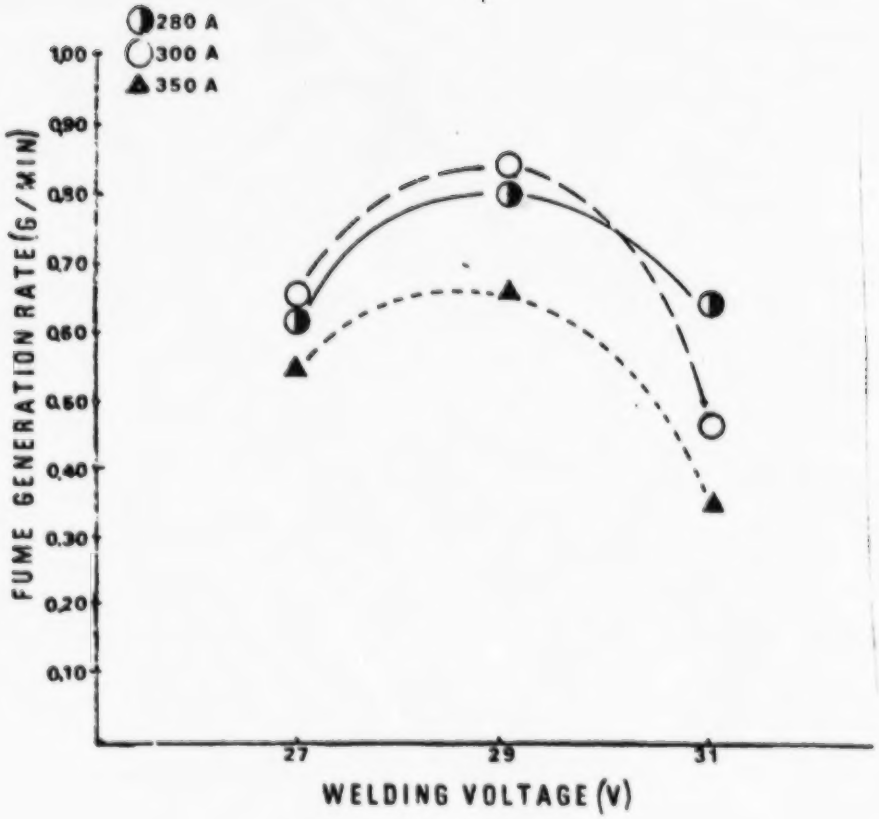


Figure 7. Average fume generation rate during welding with Monel 451 electrode at 280A, 300A and 350A welding current. All welds deposited with 50% argon + 50% Helium.

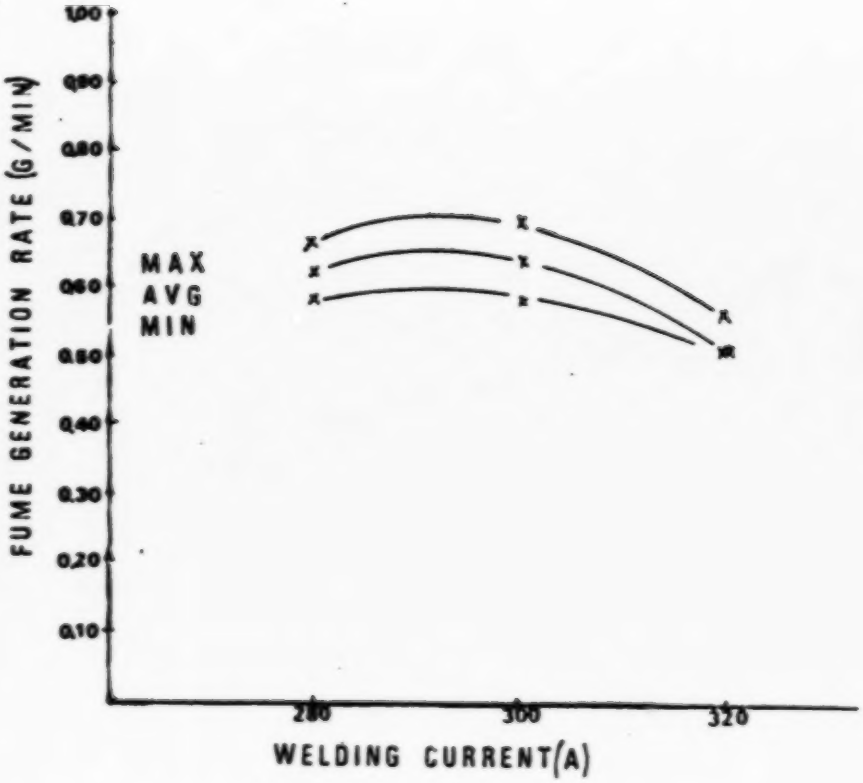


Figure 8:
Fume generation rate during welding with Monel 451 electrode at 27V welding voltage while using 50% Argon + 50% Helium.

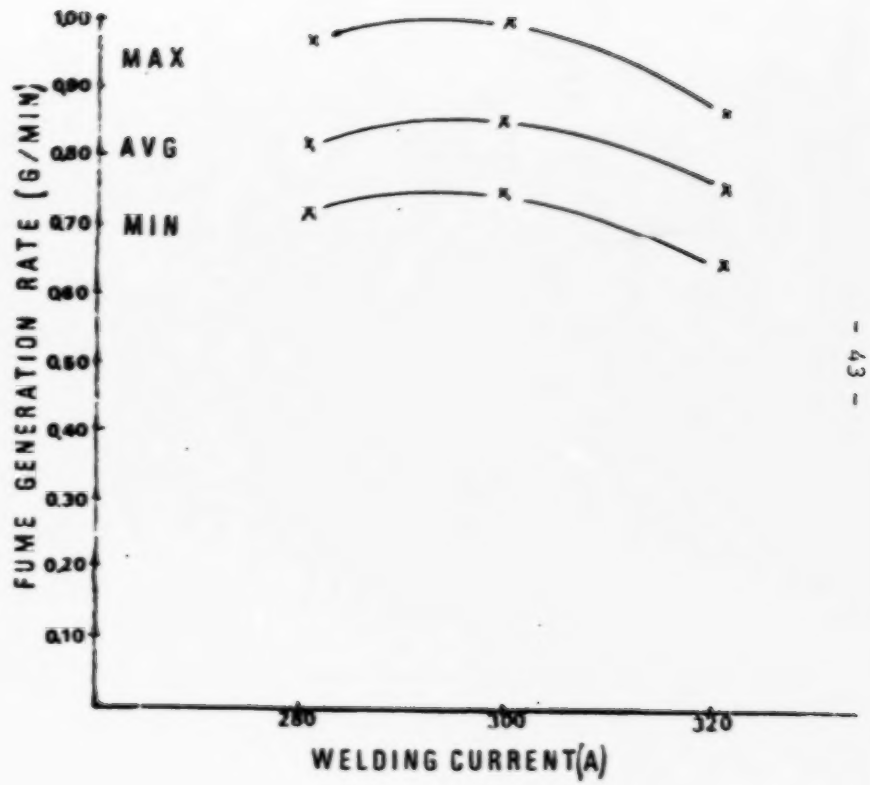


Figure 9:
Fume generation rate during welding with Monel 451 electrode at 29V welding voltage while using 50% Argon + 50% Helium.

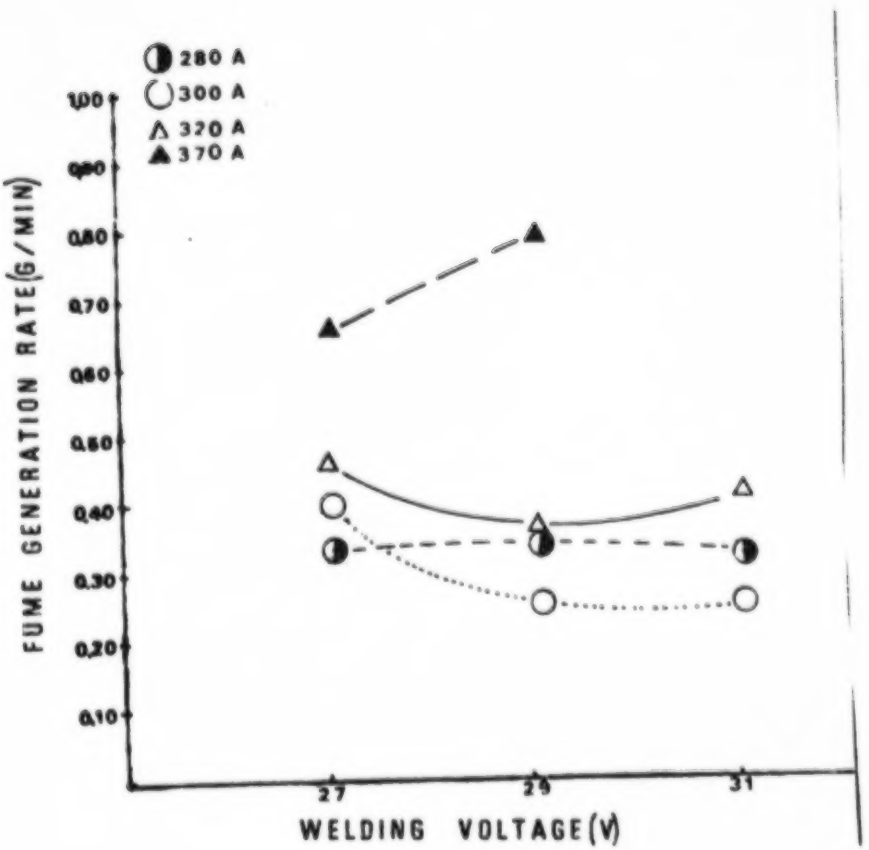


Figure 10. Average fume generation during welding with Cuprotrode 521 electrode at 280A, 300A, 320A and 370A welding current while using 100% Argon.

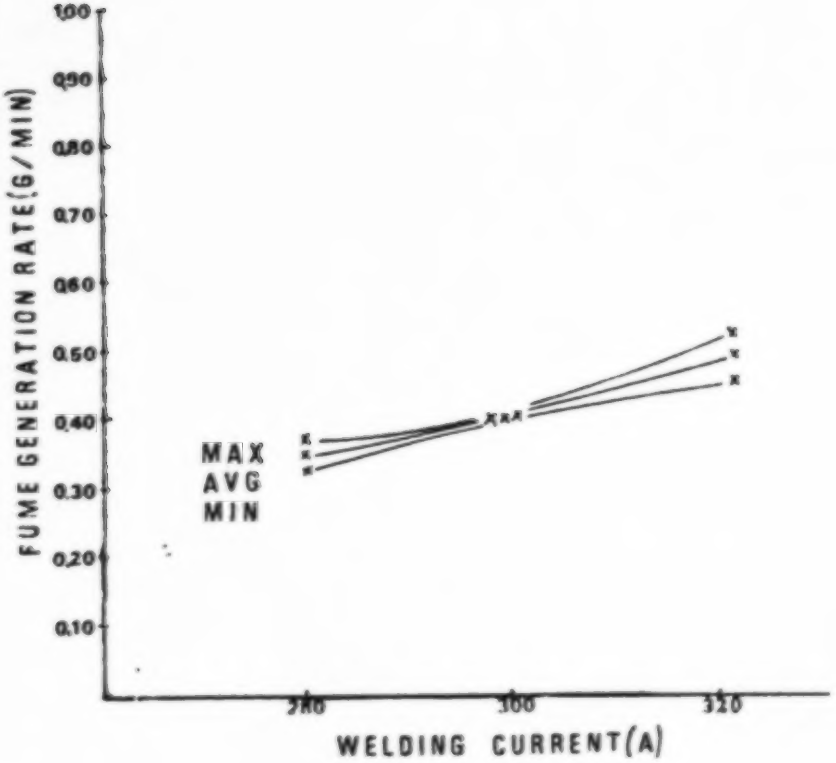


Figure 11:
Fume generation rate during welding with Cuprotrode 521 electrode at 27V while using 100% Argon as shielding gas.

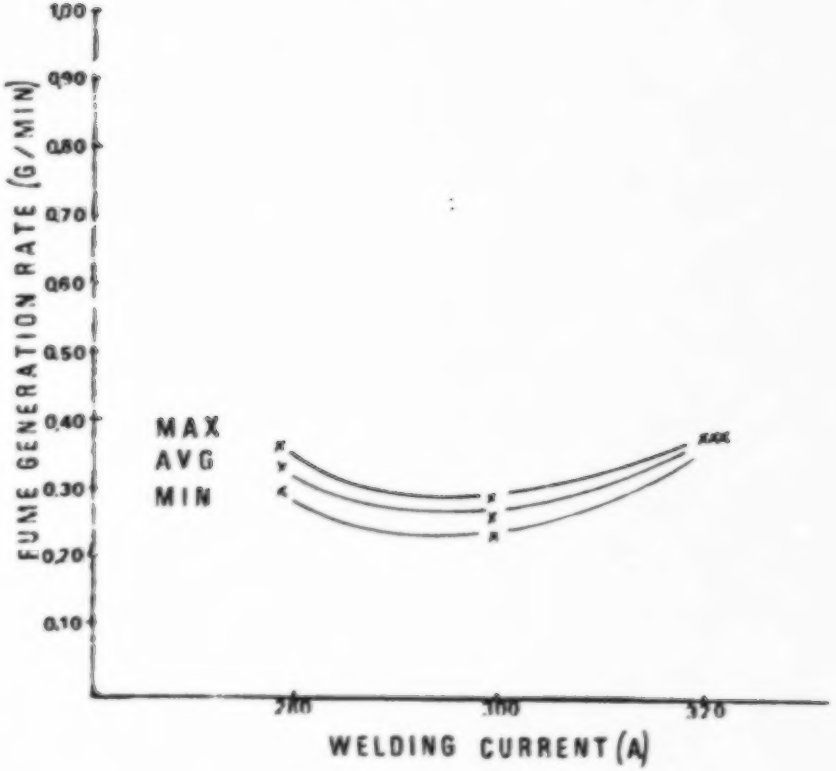


Figure 12:
Fume generation rate during welding with Cuprotrode 521 electrode at 29 V while using 100% Argon as shielding gas.

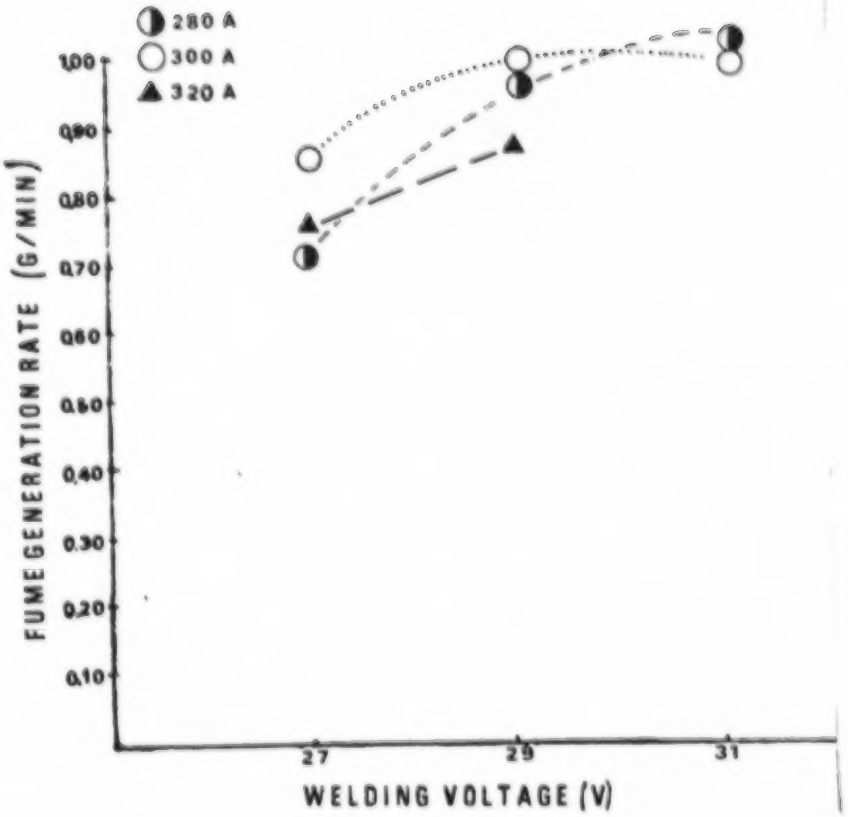


Figure 13. Average fume generation rate during welding with Cuprotrode 521 at welding currents 280A, 300A and 320A with 50% Argon + 50 Helium.

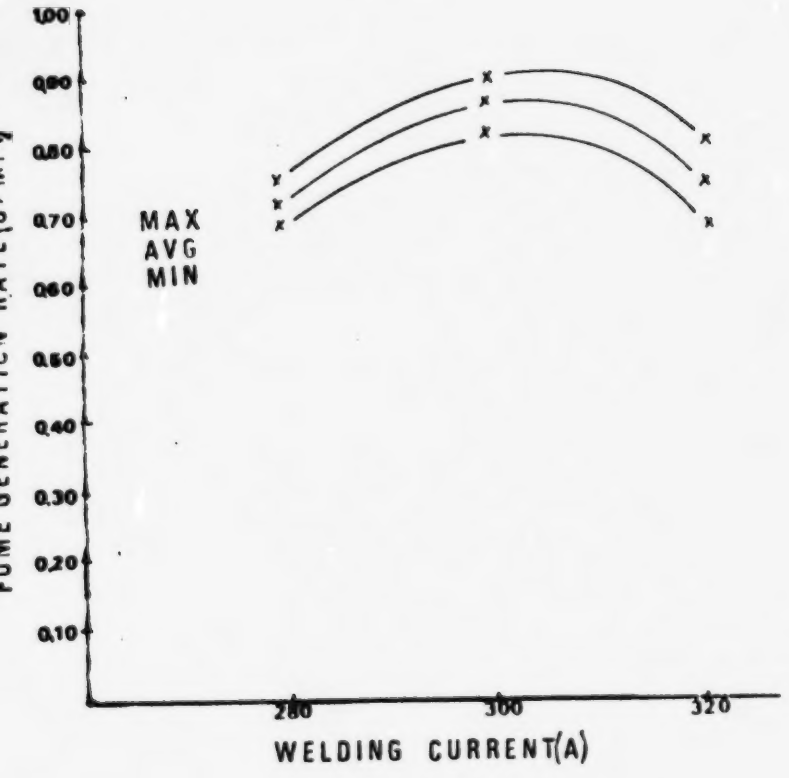


Figure 14:
Fume generation rate during welding with Cuprotrode 521 electrode at 27V while using 50% Argon + 50% Helium.

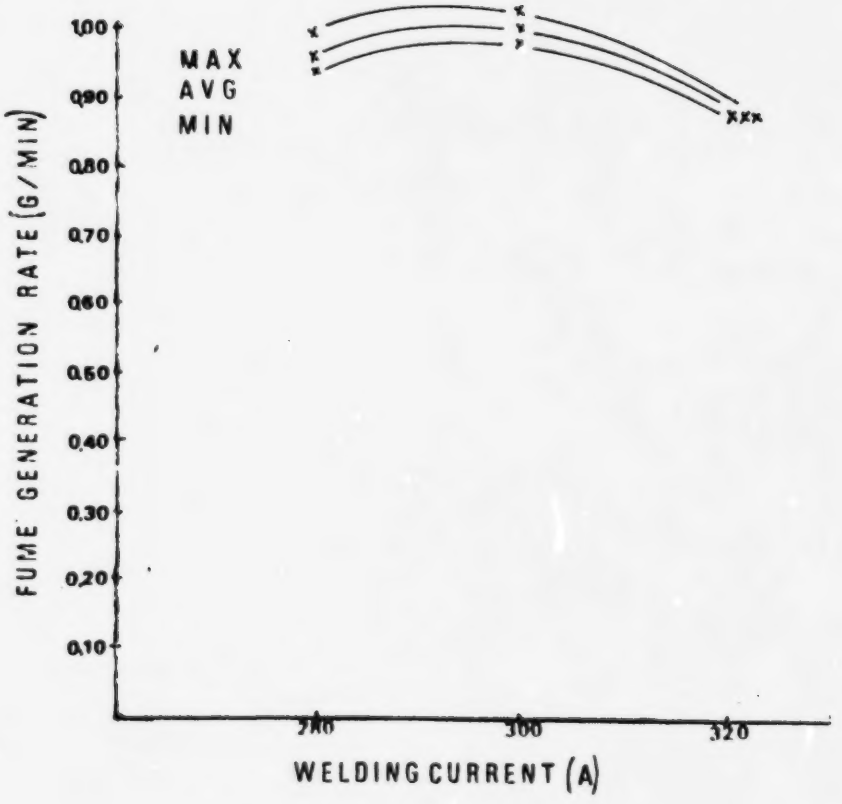


Figure 15:
Fume generation rate during welding with Cuprotrode 521 electrode at 29 V while using 50% Argon + 50% Helium.

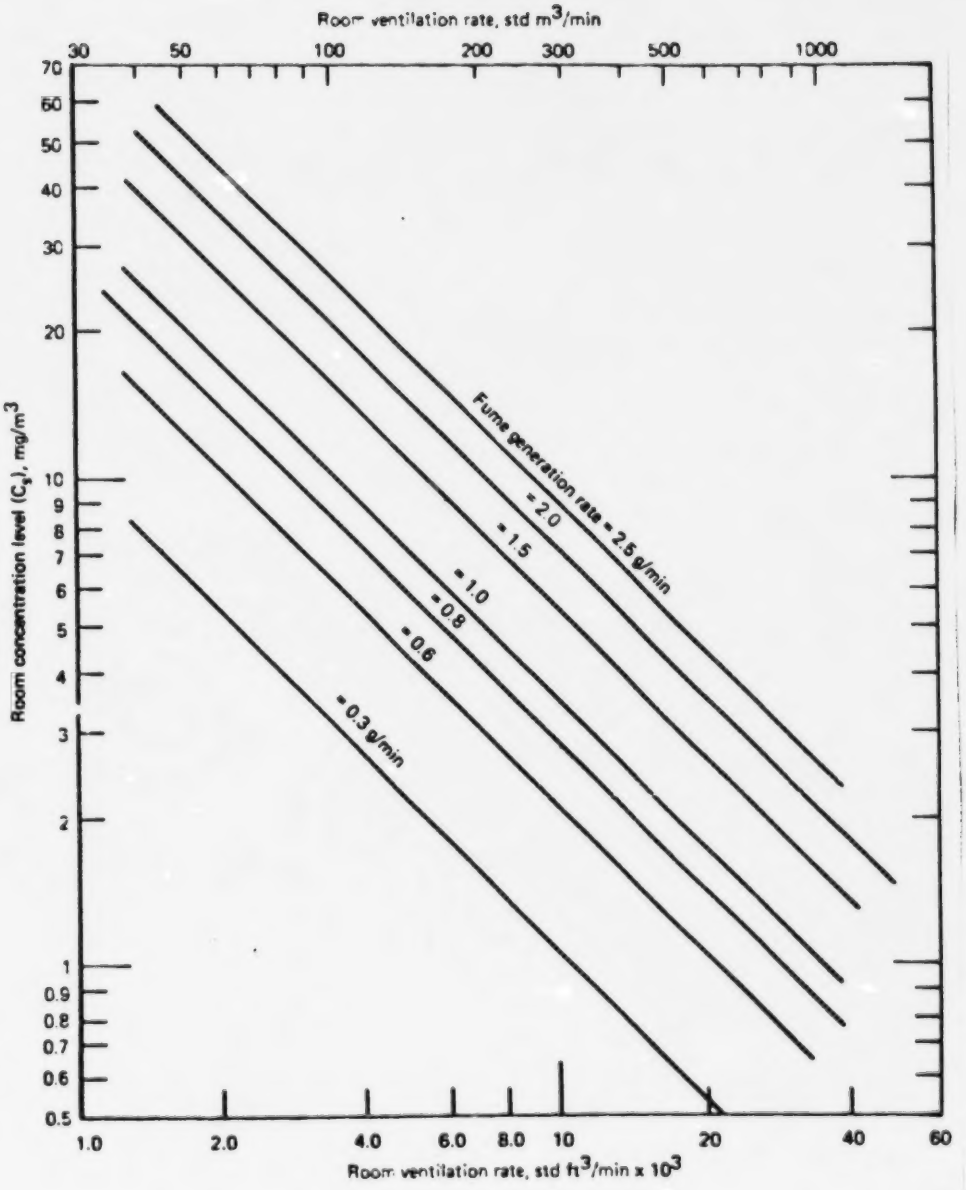


Figure 16. General root ventilation requirements for various welding fume generation rates. (2)

APPENDIX A

TABLE A

Physiological response of the body to welding fume (Lanau, 1974)

Class A	Class B	Class C	Class D	Class E	Class F
Acute Respiratory	Chronic Respiratory	Acute Systemic	Chronic Systemic	Irritant to Skin, Eyes	Relatively Inert
Chromium	Nickel	Copper	Lead	Chromium	Iron
Copper		Lead	Magnanese	Nickel	Aluminium
Nickel		Manganese	Cadmium	Vanadium	Tin
Manganese		Nickel	Fluorides	Aldehydes	"Residual Fume"
Nitrogen-Dioxide		Zinc			
Ozone					
Vanadium					
Zinc					
Cadmium					
Fluorides					
Cobalt					
Aldehydes					

APPENDIX B

TYKRON

Tykron is a progressive Canadian Company specialising in the design and manufacture of efficient industrial air cleaning equipment.

The TYKRON equipment is based on the Non-Electronic principle of air cleaning, which outperforms conventional electronic systems. The Tykron principle is based on a balanced filtration design which eliminates fluctuating efficiency and high maintenance.

Principal design criteria were:

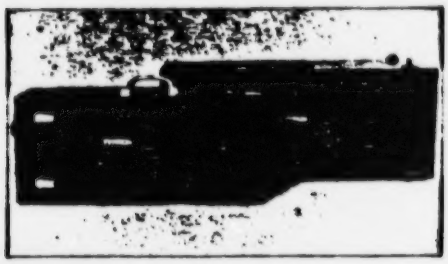
- ☐ to design equipment which would maintain a constant high efficiency
- ☐ to design equipment which would require minimum maintenance.
- ☐ to design equipment which would collect all particulate, including dielectrics such as lead, free silica, asbestos, etc. which are resistant to ionisation by electronic systems.

All Tykron units are based on a four stage filtration system, balanced to guarantee the high efficiencies shown in the Stage 4 filter section below.

For an air cleaning system to work efficiently it is essential that it be properly applied. Tykron offers back-up engineering and technical staff to ensure that the system specified will give the maximum efficiency, energy saving and low maintenance features for which it has been designed.

Stage 1 Prefilter	Washable, permanent aluminum stacked construction rated 90% efficient at 5 micron.
Stage 2 Trifilter	Throwaway pad, reduces maintenance and protects the Secondary. 30% efficient at 1.0 micron to ASHRAE tests.
Stage 3 Secondary	Disposable filter. 90% efficient at 1.0 micron to ASHRAE tests. Has a UL. C1 2 fire rating.
Stage 4 Final	Absolute (HEPA*) filter. Each filter DOP tested: 95% min. at 0.3 micron for AIR STANDARD and 99.99% at 0.3 micron for PHASE IV. Disposable filter. Has a UL. C1.2 fire rating.
Filter Seal	Units have a filter sealing design which eliminates by-pass of particulate thus assuring overall

PHASE IV



Four Stage Weld Fume Eliminator

The **Phase IV** gives absolute filtration of weld fume and other hazardous particulate.

Source capture obtained by use of nozzles, hoses or the SMG Smokeless Mig gun is preferred by welders who weld in areas which cannot be controlled by stationary units.

Main benefits are: ☐ low maintenance ☐ guaranteed efficiency of 99.99% at 0.3 micron. ☐ flexibility of draw with the two independent motors ☐ no motor overheating ☐ washable pre-filter ☐ gas filter (optional) controls contaminates such as Nitrogen Dioxide, Oxide, Textroxide, Carbon Monoxide, Ozone, Phosgene, Trichlorethelyne, etc. Consult Tykron for other gas and vapour applications.

SMG Smokeless MIG Gun

Tykron designed the SMG to be used in conjunction with the PHASE IV to provide over 90% source capture of welding fume.

Basic features of the gun are: ☐ adjustable vacuum flow control for optimum control of weld fume ☐ light weight, high temperature, gun handle ☐ highly flexible and light-weight cable hose assembly ☐ custom-designed low rib hose for easy manouverability over weldments ☐ complete extraction and welding capability in one gun – no add-on vacuum hose. ☐ innovative miniature hood design with adjustable control that virtually eliminates porosity at fume extraction rates above 90% ☐ cable contains an integral strain relief (at feeder) to permit smooth wire feed ☐ cost saving – cable does not require standard liner when used with 5/64, 3/32, 7/64 and 1/8 welding wires.

PHASE IV

Phase IV Series: Standard Features:

	Compact	Standard
CFM	Motor 1–80 Motors 1 & 2–160	Motor 1–80 Motors 1 & 2–160
Power Requirements	115 V. Single Phase 15 amp service	115 V. Single Phase 15 amp service
Weight	40 lb. (18 kg)	75 lbs. (34 kg)
Length	37" (94 cm)	37" (94 cm)
Height	15" (38 cm)	16" (41 cm)
Width	9" (23 cm)	12" (31 cm)
Filters	as shown on inside front page.	
Hose	15 ft. 1¾" I.D.	

Options:

Gas Filter	Contains Purafil a patented composition of activated alumina impregnated with potasslum permanganate.
Hose	available in lengths up 50 ft.
Nozzles	S.16 16" slot nozzle S.28 28" slot nozzle S.13 13" slot nozzle F.35 3½" funnel nozzle 468 pipe nozzles 1018 pipe nozzle 2030 pipe nozzle
Y Connector	

Tykron International Ltd.
3241 Kennedy Road, #9
Scarborough, Ontario,
M1V 2J8
Toronto: 416 298 6923
Montreal: 514 766 2227

Warranty:

Tykron warrants the equipment for parts and workmanship for a period of one year from date of original purchase. This warranty does not apply to products subject to any accident, alteration, abuse or misuse.

Warranties on equipment not of seller's manufacture, are limited to terms of warranty furnished by seller's supplier's.

All specifications are subject to change without notice. Product may not be exac as illustrated.

Distributed By:

ADDENDUM

This addendum describes a method to calculate the weight percent of consumable which is converted to airborne fume. the following quantities are required in the calculation:

Linear weight of the consumable (W) g/mm

Wire speed (S) mm/min

Fume generation rate (R) g/min

The weight percent is then calculated as:

$W\% = (R/(W \times S)) \times 100\%$

The linear weight of each consumable was determined to be as follows:

Monel 451; W = 0.0165 g/mm

Cuprotrode 521: W = 0.0173 g/mm

As an example, taking the average fume generation rate of 0.21 g/min from Table 3 for the first test condition, the following weight percent fume emission is determined.

$W\% = (0.21/(195 \times 0.0165) \times 100\%$

$= 6.5\%$

Thus for this test condition 0.065 g of fume is produced per gram of consumable used.

POOR

QUALITY

ORIGINAL